Morphaces: Exploring Morphable Surfaces for Tangible Sketching in VR

Payod Panda
North Carolina State University
Raleigh, USA
ppanda@ncsu.edu

Charles Ho
North Carolina State University
Raleigh, USA
cho22@ncsu.edu

Derek Ham
North Carolina State University
Raleigh, USA
daham@ncsu.edu

ABSTRACT

This pictorial documents our inquiry into the design and utility of morphable surfaces to provide tangible feedback while sketching in Virtual Reality (VR). We explored materials and various structures that could enable a surface to morph. We designed and implemented the Morphace ecosystem that includes 3D printed accessories that enable handheld and desk-mounted pen-and-surface interaction for the Oculus Quest VR device. We present this preliminary exploration with the hope that this will be explored further by the design and broader HCI community.

Authors Keywords

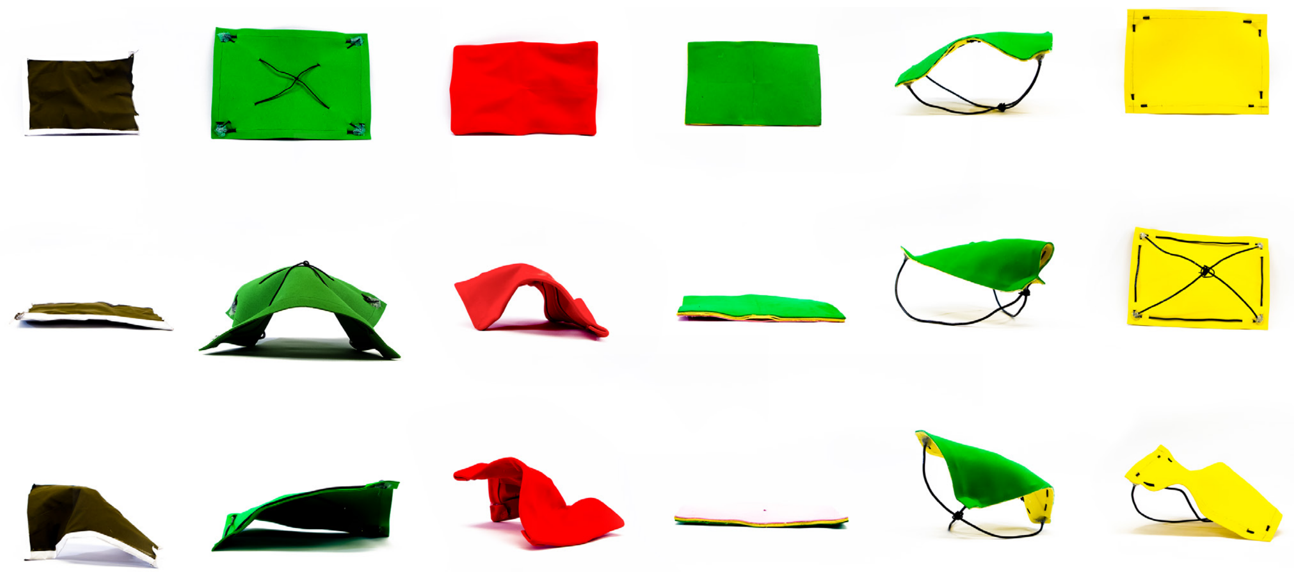
tangible sketching; substitutional reality; VR sketching; morphable surface

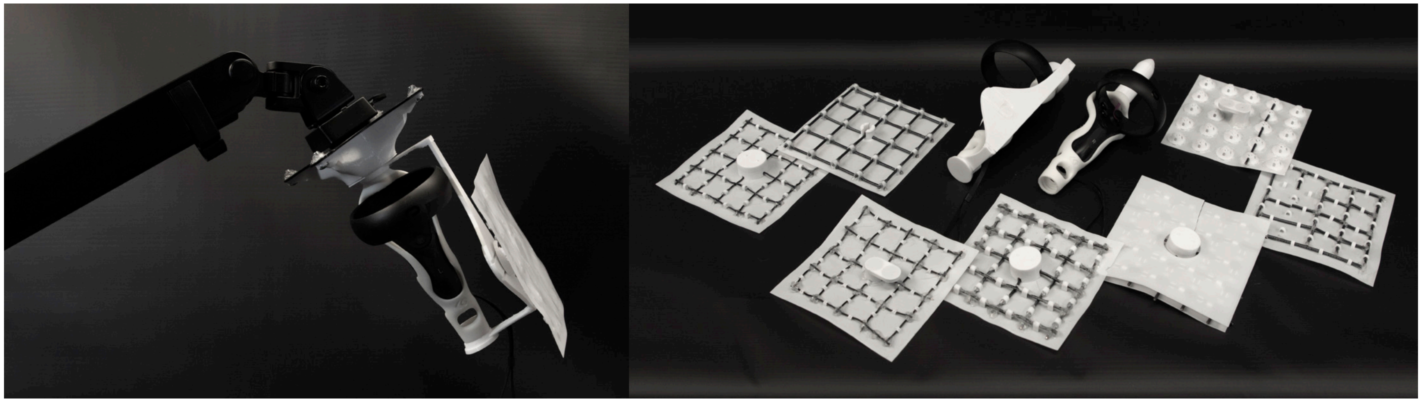
CCS Concepts

•Human-centered computing → Human computer interaction (HCI)

C&C '21, June 22–23, 2021, Virtual Event, Italy

ACM ISBN 978-1-4503-8376-9/21/06 $15.00
https://doi.org/10.1145/3450741.3465387





INTRODUCTION

With the rise of low-cost consumer VR headsets, immersive 3D drawing has been made more accessible to the general public [3]. Many consumer apps enable the user to draw in mid-air (Figure 1), which has also been explored in the HCI research community [2, 5]. However, as compared to 2D drawing, 3D mid-air drawing in VR is challenging. Prior work has shown that VR mid-air sketches are less accurate than their 2D counterparts [1]. One of the reasons for this is the lack of a physical surface while creating mid-air 3D drawings [1, 3, 13]. While resaerchers have explored the use of physical surfaces such as tablets and other rigid planar surfaces in VR for sketching and modeling [6, 17], explorations around morphable surfaces for this application remains limited. Our goal with this pictorial is to engage the design and HCI community to open discussion on the utility of morphable surfaces for sketching in VR. We feel this is a rich area for exploration.

MOTIVATION

In the physical world, we can touch and feel objects. For instance, artists that want to paint miniatures are able to do this by holding a physical brush, and painting on a physical surface (Figure 2). The tangibility of the object tells the artist that they are touching the surface and are painting on it. How can we bring this sensation to VR?

RELATED WORK

Over the years, several researchers have explored freehand gestures as an input technique for 3D sketching [2, 4, 5, 19, 20]. However, freehand 3D sketching suffers from drawbacks like reduced accuracy [1, 19]. The lack of haptic feedback also reduces immersion [16]. To compensate for these shortcomings, researchers have implemented various interaction techniques for mid-air as well as physical surface-supported sketching.

For instance, Smart3DGuides [13] offers an **unconstrained mid-air visual guide** to its users. Even without any haptic feedback, these guides helped the user draw more accurately [13]. Kim et al. explored the creation of a rough sketching guide by using mid-air hand gestures to make scaffolding surfaces [11]. The user could add details to the rough scaffold by using pen input.

Researchers have also explored **vibrotactile and force feedback** for mid-air sketching. In particular, the Phantom haptic device has been a popular choice for active force feedback in mid-air drawing, for instance in [10]. In more recent work, VRSketchPen [7] offers vibrotactile feedback to emulate surface texture, and pneumatic force feedback to emulate contact pressure of the pen against a virtual drawing surface. However, implementing such a solution is costly, and is not feasible for the average user.

Finally, the use of **physical surfaces for constraining user input** has also been explored. VRSketchIn [6] and SymbiosisSketch [2] use a combination of pen-and-tablet input in conjunction with mid-air sketching. While these projects provide haptic feedback for drawing, the physical drawing surface remains flat and can't conform to the shape of the desired virtual object. Wacker et al. [18] explore the use of physical objects as a basis to sketch on within AR, however using physical objects is too specific and requires the use of a physical object for every virtual model the user wants to sketch.

DESIGN RATIONALE

Based on the above, we developed the following design rationale that have guided our investigation:

1. One-to-many correlation between physical to virtual object. The same physical object should be able to represent a multitude of virtual objects.

2. Low-cost, accessible designs. Should not use exotic materials.

3. Should work with existing VR devices. Do not create a new VR device or controllers--use passive haptics and proxies.

Figure 1. Mid-air drawing enables users to sketch 3D objects without support.

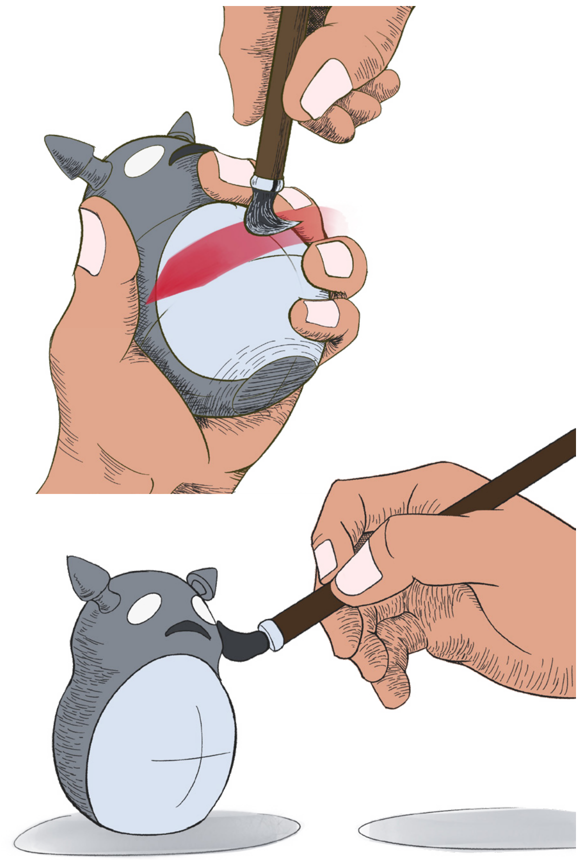


Figure 2. To paint miniatures, artists can use a physical brush and surface.

MATERIAL AND STRUCTURE EXPLORATIONS

Exploration 1

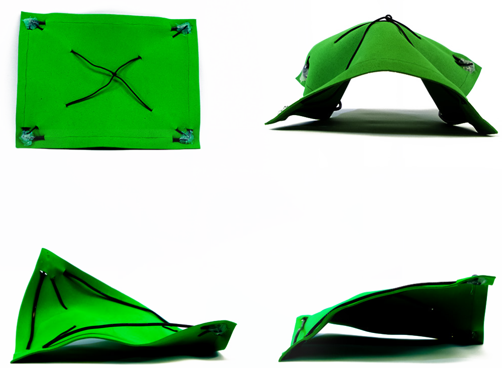
We started our material and structural explorations with paper and a thin 24 AWG wire. However, this proved too flimsy and we quickly switched to foam. This prototype has an X wire skeleton, that weaves in-and-out of the foam surface.

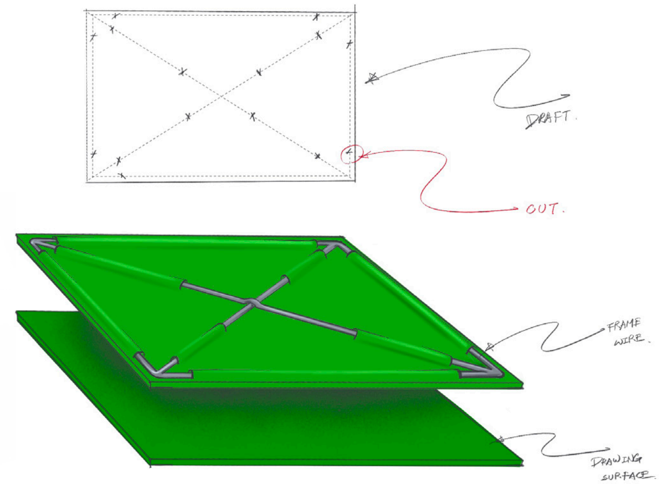
Pros:

This structure only uses a single layer of foam, and is very quick to put together.

Cons:

However, the structure exposes wires on both sides of the surface, making drawing on it impossible. The structure did not hold shapes very well, owing to the relatively thin 18 AWG wire used. Additionaly, the structure would morph typically with a kink in the middle of the structure at the intersection of the cross.





Exploration 2

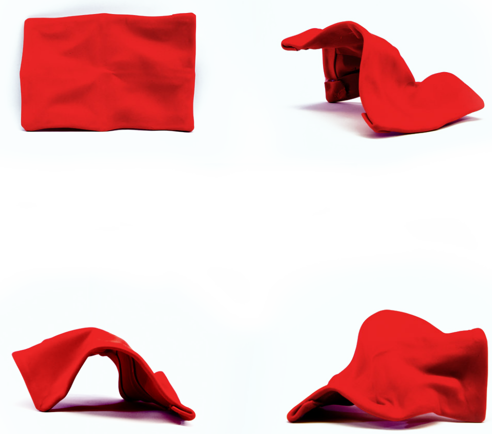
Our second prototype has a grid shaped wire skeleton, that sits on a separate layer from the foam surface. We switched to a more substantial 12 AWG wire, and used separate foam cutouts to contain the wire skeleton.

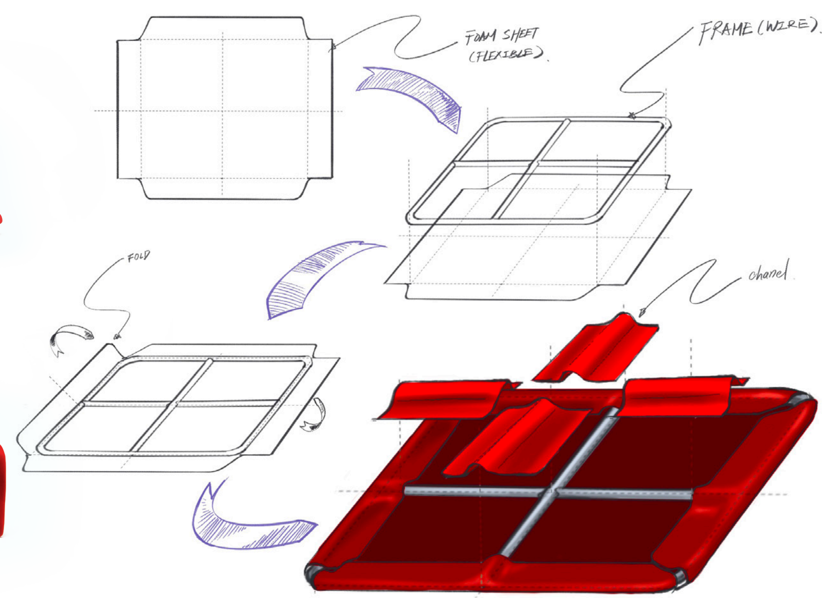
Pros:

This surface morphed and held its shape significantly better than Exploration 1.

Cons:

Due to the double layering of the foam at specific regions, the density of the surface is uneven which could be perceived when running a pen over the surface.





Exploration 3

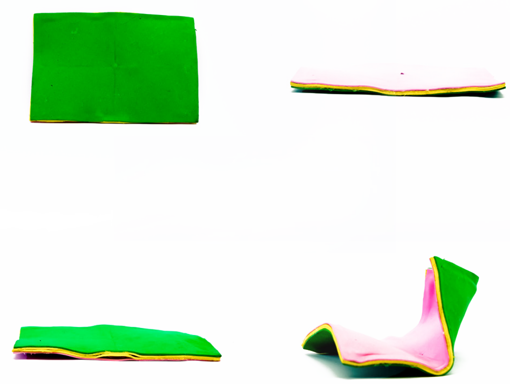
This exploration was a refinement of Exploration 2. We sandwiched the 12 AWG wire between two layers of foam (green and pink), and filled the empty space around the wires with yellow foam.

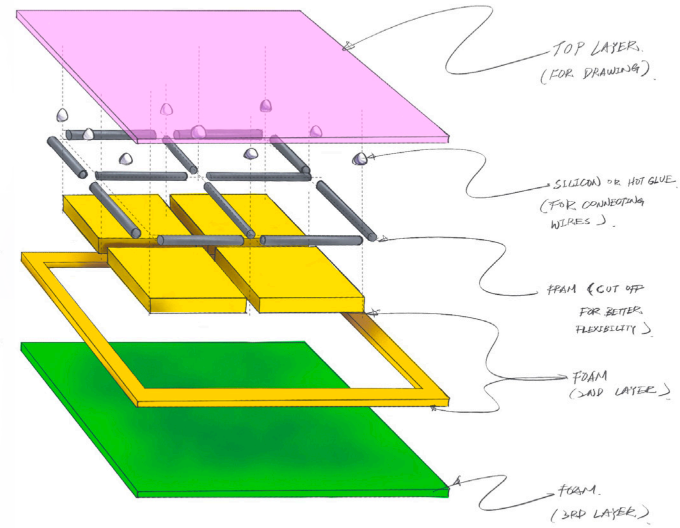
Pros:

This structure had a very even material distribution.

Cons:

However, because the full wire skeleton was on a single layer, we had to cut them up at the joints. This led to the formation of kinks at these joints, and we learnt that it is important to maintain the full length of wire along an edge to form the skeleton.





Exploration 4

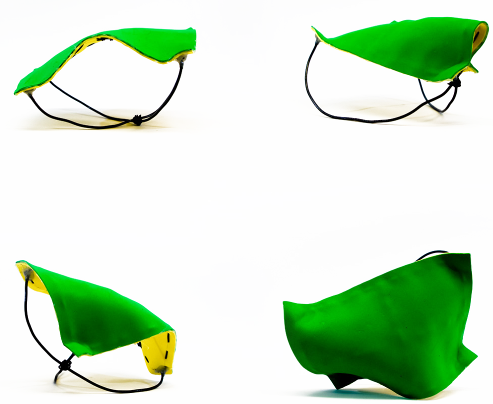
We stitched together two pieces of foam using 24 AWG wire. The corners were held together with a tent-like structure made of 12 AWG wire. The “tent” was held together at the intersection with a loop, and each acted as a rail for the other to slide over. Sliding them to different locations changed the shape of the morphed surface.

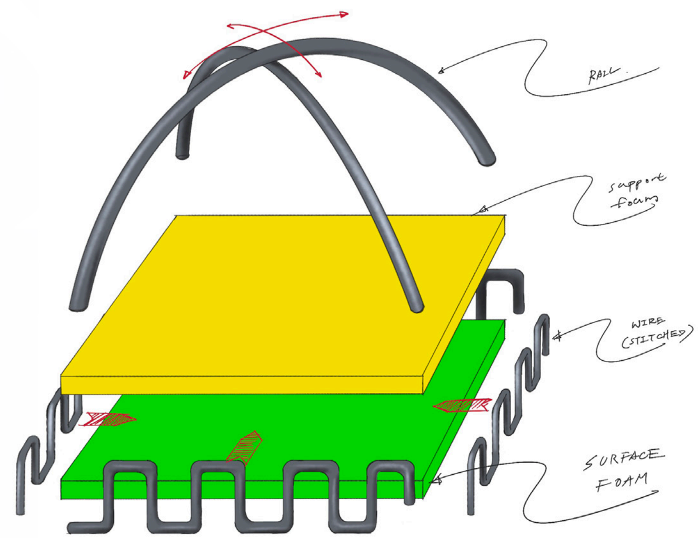
Pros:

This structure had a limited set of possibilities for the shapes it could assume, since it was constrained by the location of the wires. This would make it easier to operationalize and represent virtually.

Cons:

However, this structure provided little support at the surface, and was too flexible against the weight of a pen or stylus. The limited surface shapes was also a limitation.





Exploration 5

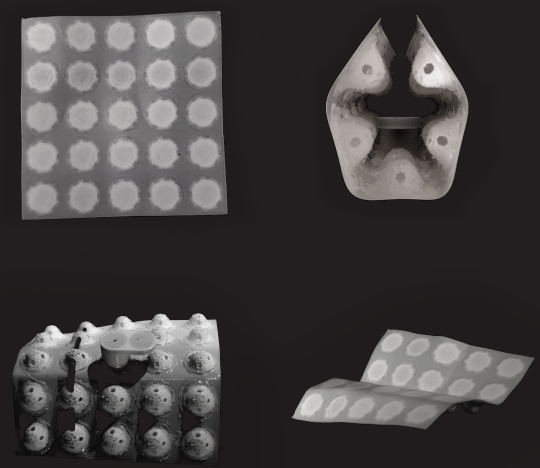
With this exploration we switched our material from foam to 3D printed PETG filament. This decision was driven by the relative softness of the foam material. The springiness of the foam made it difficult to write on. Our first 3D printed structure used a 5x5 grid of dpme-like structures, that had holes to enable the creation of a wire mesh. We used 18 AWG wire for this.

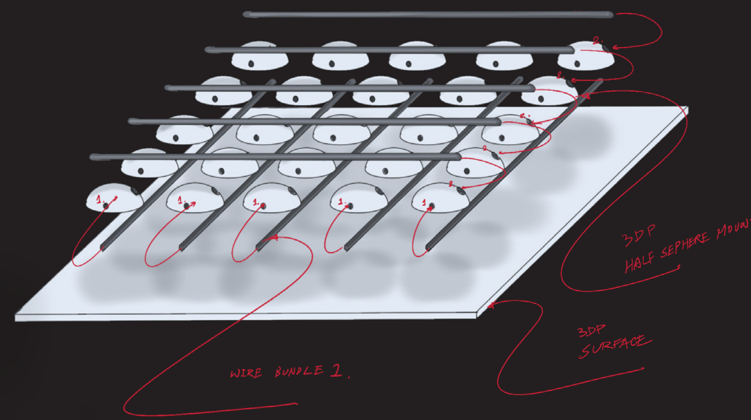
Pros:

Compared to foam the PETG was smooth, hard, and flexible, an ideal candidate.

Cons:

The dome shapes were too large, which made it hard to curve the surface smoothly (see image, top-right photo).





Exploration 6

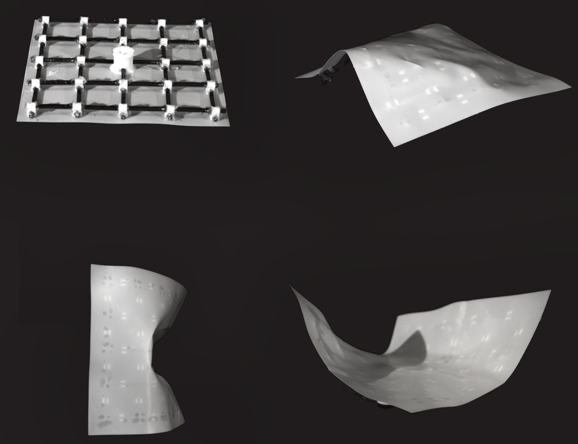
We switched out the dome structures from exploration 5 to smaller hook-like structures. We tried this structure with both 12 and 18 AWG wires.

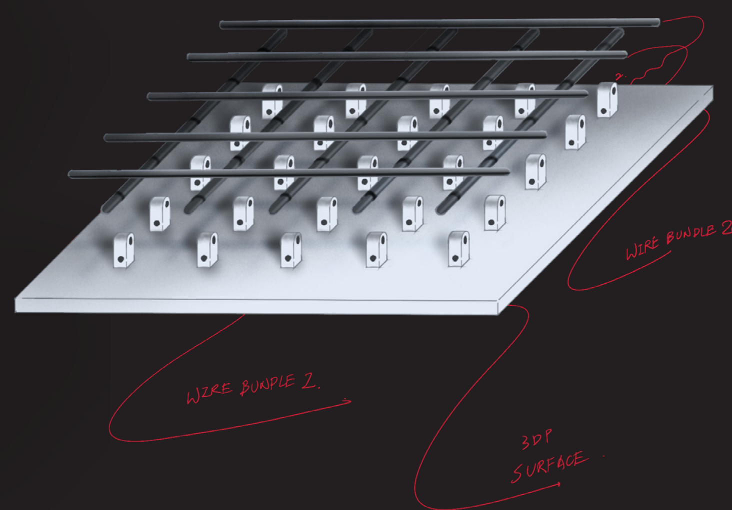
Pros:

This structure proved fairly versatile. The mount points had a small footprint, enabling the surface to morph nicely. The 12 AWG wire was thick and provided a very rigid structure, but was hard to morph. The 18 AWG wire was easier to morph, but at the same time changed shape easily when force was applied to the surface.

Cons:

The back side of this surface had the wires exposed, which meant the user would be able to feel the wires when morphing this surface.





Exploration 7

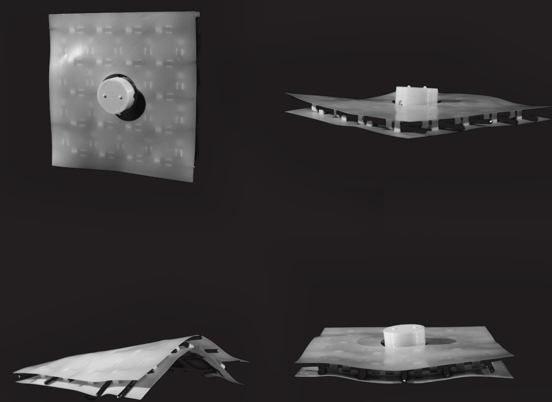
We wanted to explore adding a second surface layer on the back side of the morphace in order to provide a more pleasant experience while holding the surface to morph. The second layer here fit the first layer like a jigsaw puzzle piece.

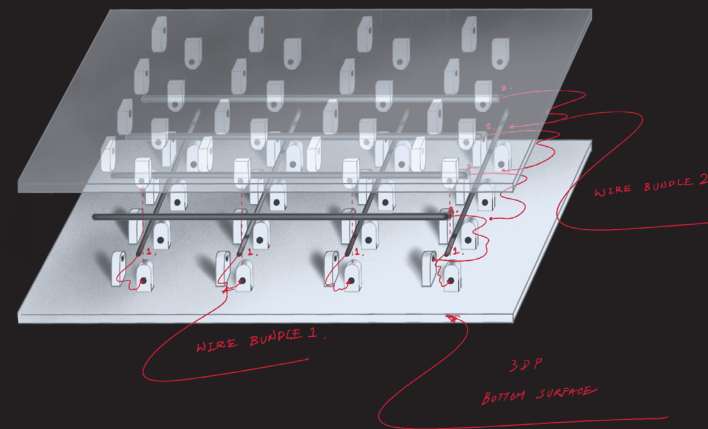
Pros:

The backside was smooth.

Cons:

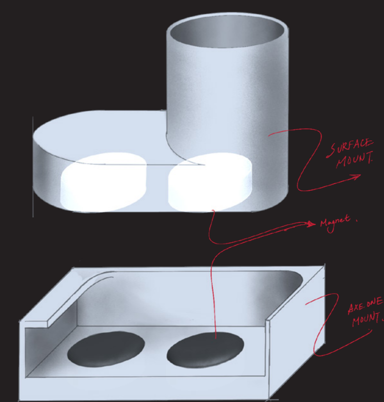
However, this structure did not work at all. The holes from the two surfaces that lined up would slide in different directions when the user tried to morph the surface. This made it mechanically impossible to keep the wire mesh inside this structure.

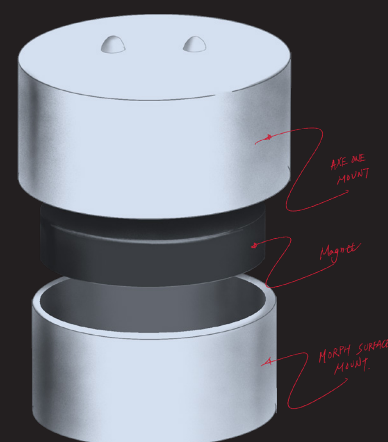


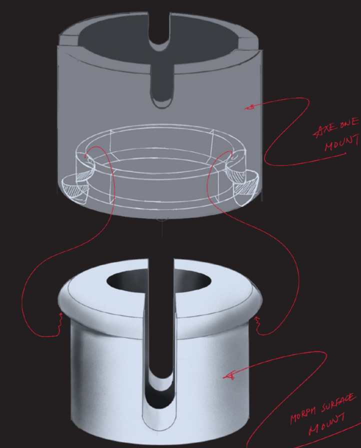


Mounting Explorations

One of the challenges with our foam explorations was the design of a mounting mechanism. Since these surfaces eventually needed to be mounted on some other device, we started exploring ways to do this with our 3D printed prototypes. This mechanism should allow the user to attach and remove the surface from the controller with relative ease. We primarily explored different configurations using magnets and mechanical snaps. A weak ceramic magnet-based mechanism wasn't strong enough for the mount, and a stronger neodymium magnet introduced interference with the functioning of the controller. A purely mechanical snap design shown in the third rendition here was used for our final design.







THE MORPHACE ECOSYSTEM

Using what we learnt from our material and structure explorations, we designed an ecosystem of tangible accessories that work with the Oculus touch controllers to provide morphable surfaces for an artist to sketch and texture on. Our system consists of four parts:

1. The Morphace morphable surface (Exploration 6), including a mounting mechanism for the surface to attach to the controller (mount #3 mechanical snap).

2. A table-mounted arm, with a mounting mechanism to hold the controller with the Morphace.

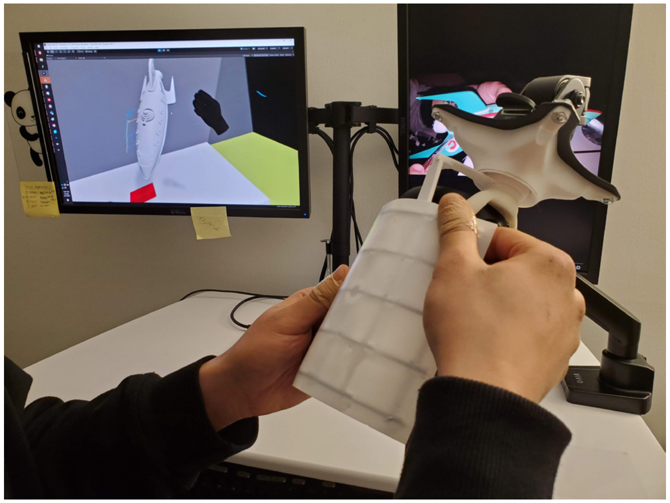
3. A 3D printed pen accessory for the Oculus touch controller.

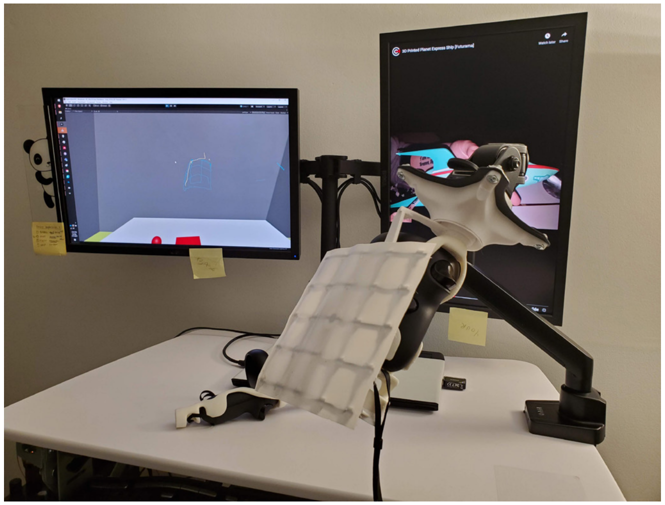
4. A simple software interface that enables the user to use the morphable surface with the Oculus Quest or Rift VR devices.

USAGE AND APPLICATIONS

Morphing the Surface

The morphable nature of the Morphace lends itself to being manipulated and taking on the shape of the surface of a variety of different objects. Expanding upon the notion of substitutional reality [16], the same physical prop can serve as a proxy for many virtual objects. This enables the artist to switch between drawing / texturing different 3D objects, or different parts of the same 3D object. For instance, part of a 3D model might be flat (like the tail wing of a space ship), and another part might be curved (like the main body of the spaceship).

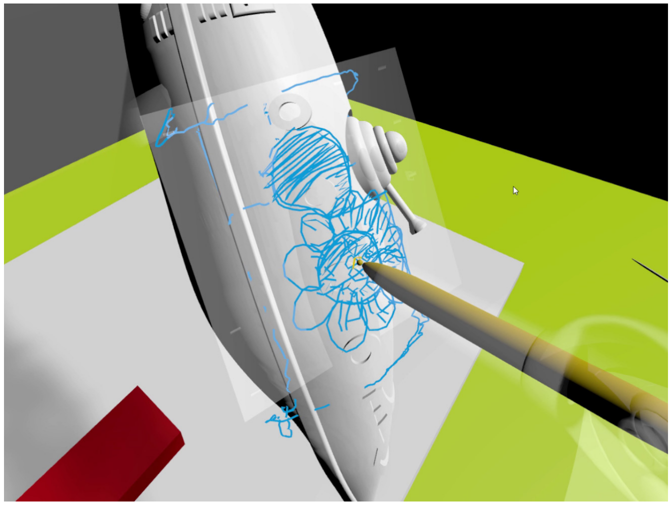




Desk Mounted Operation

The Morphace ecosystem allows the surface to be mounted to a desk-mounted mechanically actuated arm. For our prototype, we used a commercially available desktop monitor mount for this purpose, and designed and 3D printed a mounting mechanism for a Quest touch controller to mount to the VESA interface offered on the monitor mount.

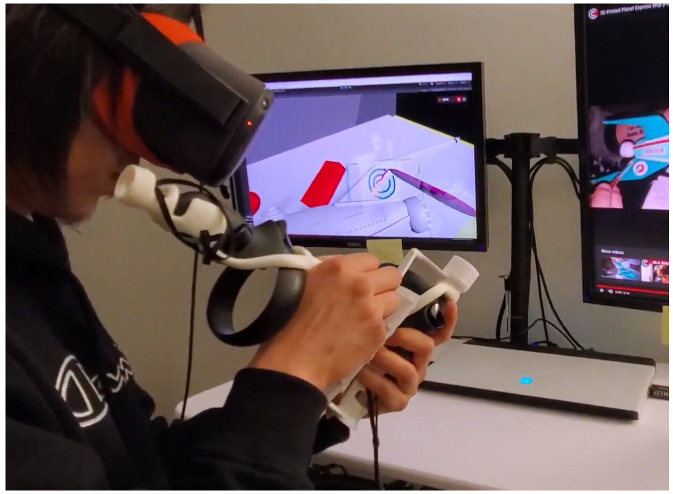
Desk-mounted operation allows the surface to remain relatively stable and grounded in the world frame of reference. The user is free to move around the arm, and the surface stays put. This is particularly useful when sketching a complex shape. Here, an artist is shown sketching

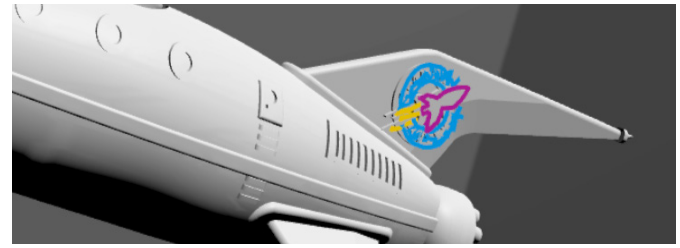


Handheld Operation

In addition to the desk-mounted operation, the Quest controller can also be detached from the monitor mount in order to enable handheld operation. This usage is similar to writing or sketching on a notepad.

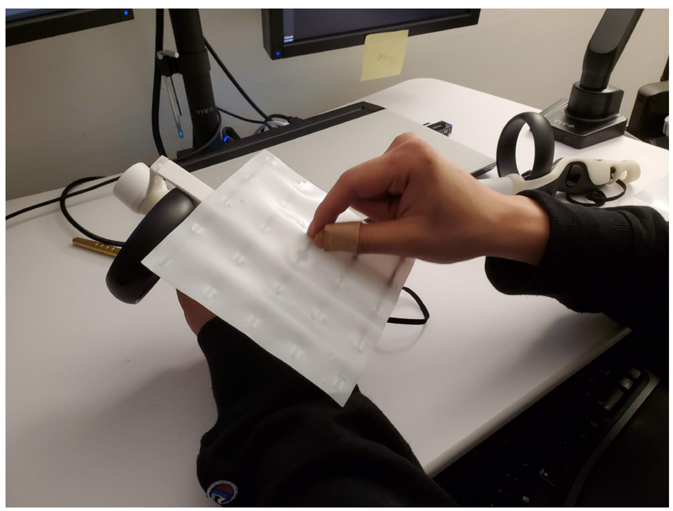
Handheld usage allows the user more flexibility in the positioning of the surface. However, since the surface is held in the user's hand, this tends to be less stable. As a countermeasure to this, the user may hold the virtual object that he or she is drawing on, so that the object moves with the user's hand. In our tests, we were able to paint fairly intricate designs on the virtual model of the spaceship (see image, top right). This can be compared to the photo of a user painting a 3D printed model of the same size (see image, right).





Hand Tracking

Our implementation uses a 3D printed pen system created for the Oculus Quest touch controllers. However, using hand tracking in the Morphace system expands our possibilities. One might imagine drawing on the surface without a need for a physical instrument at all, or alternatively, the user could use any instrument that they're already familiar with, like a pen on the morphed surface. Additionally, hand tracking frees up both of the user's hands, enabling them to manipulate the surface as they see fit on-the-go.



DISCUSSION AND LIMITATIONS

The intent of this work is to spark discussion and exploration in the community, rather than showcase a completed implementation of a system. As such, our work has several limitations revolving around a few themes discussed here. These should prove fruitful areas for future explorations.

Equipment Ergonomics

One of our design rationales was the use ofaffordable and readily available materials to fabricate the required accessories. Additionally, we decided to use a pre-existing VR device rather than design a custom solution. While this presented us with some technical limitations, this was in the interest of easy replication by other researchers as well as home users. However, using the 3D printed pen accessory with the Oculus Quest controller was unwieldy. The weight balance was too skewed towards the back, and the user had to exert extra force in order to hold the pen stable. Future work should explore better weight distribution structures while still using affordable materials.

Location Tracking

Our system leveraged the built-in 6-DOF (Degrees-of-Freedom) tracking already implemented in the Oculus Quest device. By attaching the surface to one of the controllers, we were able to accurately track the location of the surface. However, the morphable surface blocked the view of the controller from the headset at some angles, which resulted in the loss of tracking.

Additionally, using one of the controllers for tracking the surface sacrificed the controller when being used in desk-mounted mode. However, it was a pleasant surprise to use in hand-held mode. Since the VR controllers are ergonomically designed to be held in a user's hand, it was more comfortable than holding a heavy tablet (eg., used in [2, 6]). It felt natural to hold the surface while drawing with the right hand, similar to how one might hold a notebook. We also implemented a few interactions on the left controller (for instance, defining the surface shape in VR), so the controller could be utilized.

Shape Tracking

In our implementation, the user must manually morph the surface, which requires both hands due to the stiffness of the surface. This means that the user can only perform this action in between sketching sessions, which was against our initial hope of the user being able to morph the surface easily on-the-go.

Even though the user can manually define a virtual representation of the morphed surface, this representation is static. One of the major limitations of our work is the lack of dynamic congruence between the physical shape of the morphed surface in its current configuration and its virtual representation. Currently we create a virtual representation of the morphable surface within VR by switching to "surface definition" mode, where the user can manually trace the shape of the surface in VR. Future work should explore one of the many ways of improving upong this, including computer vision, electronics, and mechanically actuated surfaces. Previous work in shape-aware interfaces [9] and mechanically actuated interfaces [14] serve as a good starting point for exploration.

Hand Tracking

One of the more exciting ways of using this system is to track the user's hands. By being able to use the user's bare hands for input rather than a controller, the user is able to interact freely with the morphed surface (physical manipulation of the surface). Additionally, tracking the user's hands and gestures might enable the user to use any tool that they desire for the process.

However, the current hand tracking algorithms that we tried with the Oculus Quest as well as LEAP Motion controllers were sub-par, resulting in frequently lost and jittery tracking. As an additional constraint, using only the Oculus Quest system only allows the user to either track their hands or the controllers. Since we are using the location of the controllers to locate the morphed surface, it is currently not feasible to use hand tracking with our implementation. A combination of using the Quest system to track the surface and the LEAP Motion to track the user's hands might be an interesting next step.

Surface Size

Finally, the size of a drawing surface plays a major part in its use by an artist. Our surface is 6" x 6" (150mm x 150mm), which is about the size of a small field journal. While this size does enable one to create strokes, it is also pretty limiting. For larger models, the user will have to reposition the surface with respect to the model in order to cover a larger area. This can be done by either moving the model (eg., for desk-mounted operation), or by moving the surface itself (eg., while using handheld operation). Additionally, we were limited in the size of the surface we could explore due to the limitation of the size of the 3D printer available to the authors.

CONCLUSION

In this pictorial we presented our preliminary explorations into the design and utility of morphable surfaces as a way of adding tangible feedback to the sketching process in VR. We utilized low cost materials and pre-existing VR hardware for these explorations, making sure that an average user with access to simple materials (foam, stiff wire) or a 3D printer will be able to create these artefacts. We present this preliminary exploration with the hope that this will be explored further by the design and broader HCI community, and spark an interest in exploring the utility of low-cost solutions for immersive media.

REFERENCES

[1] Rahul Arora, Rubaiat Habib Kazi, Fraser Anderson, Tovi Grossman, Karan Singh, and George Fitzmaurice. 2017. Experimental Evaluation ofSketching on Surfaces in VR. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17. ACM Press, New York, New York, USA, 5643–5654. https://doi.org/10.1145/3025453.3025474

[2] Rahul Arora, Rubaiat Habib Kazi, Tovi Grossman, George Fitzmaurice, and Karan Singh. 2018. SymbiosisSketch: Combining 2D & 3D sketching forde-

signing detailed 3D objects in situ. In Conference on Human Factors in Computing Systems - Proceedings, Vol. 2018-April. Association for Computing Machinery. https://doi.org/10.1145/3173574.3173759

[3] Mayra Donaji Barrera Machuca, Wolfgang Stuerzlinger, and Paul Asente. 2019. The effect of spatial ability on immersive 3D drawing. In C and C 2019 - Proceedings of the 2019 Creativity and Cognition. 173–186. https://doi.org/10.1145/3325480.3325489

[4] Mark Billinghurst, Sisinio Baldis, Lydia Matheson, and Mark Philips. 1997. 3D Palette: A virtual reality content creation tool. In ACM Symposium on Virtual Reality Software and Technology, Proceedings, VRST. 155–156. www.vsl.ist.ucf.edu/-polyshop/

[5] Michael F. Deering. 1995. HoloSketch: A Virtual Reality Sketching / Animation Tool. ACM Transactions on Computer-Human Interaction (TOCHI) 2,3, 220–238. https://doi.org/10.1145/210079.210087

[6] Tobias Drey, Jan Gugenheimer, Julian Karlbauer, Maximilian Milo, and Enrico Rukzio. 2020. VR-SketchIn: Exploring the Design Space of Penand Tablet Interaction for 3D Sketching in Virtual Reality. In Conference on Human Factors in Computing Systems - Proceedings, Vol. 20. https://doi.org/10.1145/3313831.3376628

[7] Hesham Elsayed, Mayra Donaji Barrera Machuca, Christian Schaarschmidt, Karola Marky, Florian Müller, Jan Riemann, Andrii Matviienko, Martin-Schmitz, Martin Weigel, and Max Mühlhäuser. 2020. VRSketchPen: Unconstrained Haptic Assistance for Sketching in Virtual 3D Environments. In Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST. https://doi.org/10.1145/3385956.3418953

[8] Daniele Giunchi, Stuart James, Donald Degraen, and Anthony Steed. 2019. Mixing realities for sketch retrieval in Virtual Reality. In Proceedings -VRCAI 2019: 17th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and its Applications in Industry. Association for ComputingMachinery, Inc. https://doi.org/10.1145/3359997.3365751 arXiv:1910.11637

[9] Tovi Grossman, Ravin Balakrishnan, and Karan Singh. 2003. An interface for creating and manipulating curves using a high degree-of-freedomcurve input device. In Conference on Human Factors in Computing Systems - Proceedings. 185–192. https://doi.org/10.1145/642643.642645

[10] Daniel F. Keefe, Robert C. Zeleznik, and David H. Laidlaw. 2007. Drawing on Air: Input Techniques for Controlled 3D Line Illustration. IEEE Transactions on Visualization and Computer Graphics 13, 5 (Sept. 2007), 1067–1081. https://doi.org/10.1109/tvcg.2007.1060

[11] Yongkwan Kim, Sang Gyun An, Joon Hyub Lee, and Seok Hyung Bae. 2018. Agile 3D sketching with air scaffolding. In Conference on Human Factorsin Computing Systems - Proceedings, Vol. 2018-April. https://doi.org/10.1145/3173574.31738122

[12] Ginam Ko, Kyoo Won Suh, Hoe Kyung Jung, and Sang Hun Nam. 2019. Spatial Drawing Framework Design for VR-Based Painting Application. International Journal of Software Engineering and Knowledge Engineering29, 5 (may 2019), 715–728. https://doi.org/10.1142/S0218194019400059

[13] Mayra D.Barrera Machuca, Wolfgang Stuerzlinger, and Paul Asente. 2019. Smart3DGuides: Making unconstrained immersive 3D drawing more accurate. In Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST. ACM, 12. https://doi.org/10.1145/3359996.3364254

[14] Ken Nakagaki, Sean Follmer, and Hiroshi Ishii. 2015. LineFORM: Actuated curve interfaces for display, interaction, and constraint. In UIST 2015 -Proceedings of the 28th Annual ACM Symposium on User Interface Software and Technology. 333–339. https://doi.org/10.1145/2807442.2807452

[15] Donald A. Schon and Glenn Wiggins. 1992. Kinds of seeing and their functions in designing. Design Studies13, 2 (apr 1992), 135–156. https://doi.org/10.1016/0142-694X(92)90268-F

[16] Adalberto L. Simeone, Eduardo Velloso, and Hans Gellersen. 2015. Substitutional reality: Using the physical environment todesign virtual realityexperiences. In Conference on Human Factors in Computing Systems - Proceedings, Vol. 2015-April, 3307–3316. https://doi.org/10.1145/2702123.2702389

[17] Hemant Bhaskar Surale, Aakar Gupta, Mark Hancock, and Daniel Vogel. 2019. TabletinVR: Exploring the design space for using a multi-touch tabletin virtual reality. In Conference on Human Factors in Computing Systems - Proceedings https://doi.org/10.1145/3290605.3300243

[18] Philipp Wacker, Adrian Wagner, Simon Voelker, and Jan Borchers. 2018. Physical Guides: An Analysis of 3D Sketching Performance on Physical Objects in Augmented Reality. In Symposium on Spatial User Interaction (SUI '18), October 13–14, 2018, Berlin, Germany. ACM, New York, NY, USA, 11 pages. https://doi.org/10.1145/3267782.3267788

[19] E Wiese, J H Israel, A Meyer, and S Bongartz. 2010. Investigating the learnability of immersive free-hand sketching. Proceedings of the Seventh Sketch-Based Interfaces and Modeling Symposium, SBIM'10 (2010), 135–142.

[20] J. Ye, R. I. Campbell, T. Page, and K. S. Badni. 2006. An investigation into the implementation of virtual reality technologies in support of conceptual design. Design Studies 27, 1 (jan 2006), 77–97. https://doi.org/10.1016/j.destud.2005.06.0023